Milk:

Light exposure and depletion of key nutrients

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Contents

Executive Summary

The most recent scientific evidence supports the consumption of cow's milk across the age spectrum as part of a healthy diet. Fresh milk contributes essential macro- and micronutrients including protein, calcium and vitamins A, B and D to the diet, that aids growth during rapid development in early childhood.

Scientific studies have demonstrated extensively that exposure of milk to light from any source has negative effects, such as loss of vitamins and protein degradation. In dairy products, especially milk, compelling evidence has been presented that exposure to light of a range of wavelengths is responsible for a significant loss of essential micronutrients required for human development and health. Recent studies have shown that exposure of milk to light from any source causes a loss of vitamins such as riboflavin (vitamin B_2). Other effects on the nutritional properties of milk have included changes in levels of retinol (vitamin A); ergocalciferol (vitamin D_2); cholecalciferol (vitamin D_3); cobalamin (vitamin B_{12}); pyridoxine (vitamin B_6); ascorbic acid (vitamin C) and protein. Consumer studies consistently show that purchasers of milk can detect off-flavours within a short period of time. This effect has been linked to exposure of light at visible wavelengths under λ500nm, which induces the strongest formation of the negative 'sunlight flavour' in milk. However, blocking these wavelengths of light does not always reduce the detrimental off-flavours.

It is recommended that retailers of milk should take measures that minimise the detrimental effects of light. The high-intensity light sources currently used in retail milk displays that includes fluorescence and LED lighting systems utilise wavelengths that are detrimental to nutrients in fluid milk.

Use of packaging material with light-barrier capability is one of the best solutions to protect milk from damaging photooxidation processes. However, manufacturers of packaging should use materials that are certified for light protection to ensure that consumers are receiving the full nutritional value of milk.

Industry Relevance

Milk is a fast-moving product in a retail setting and a significant consumer product due to its high nutrient content. However, due to high-intensity lighting systems in retail stores, the nutrient value of milk can be severely affected. Light from all sources, including natural sunlight and artificial sources, such as fluorescence or light emitting diodes (LEDs), increases the nutrient loss in milk over a relatively short time scale of 25 minutes. LED lighting systems are rapidly developing as the dominant lighting system deployed in dairy retail cases. These bright lights are typically chosen to best exhibit milk products. However, high intensity LED lighting can drive detrimental oxidation processes which can accelerate loss of freshness of milk. This process includes vitamin and protein degradation which can alter the organoleptic properties and shorten the shelf-life of the product.

To meet the challenge of stemming the decline in consumption of fluid milk, the dairy industry must take a systematic approach to identifying and correcting for factors that negatively affect consumer experience of fluid milk quality and light degradation of essential nutrients.

Additionally, in order to avoid excessive wastage retailers should strive to find solutions to protect milk products and preserve the nutrient content for the benefit of consumers. A recommendation would be to utilize packaging design that has demonstrated and been certified for light protection performance.

Consumer Summary

This report recommends that milk should be packaged in certified materials for light protection which preserve the nutrients in milk, so that consumers can have confidence in the product they purchase and that milk contains all the nutrients they expect.

Milk is a natural food that forms a vital part of the daily diet for many consumers. It effectively provides many of the essential nutrients including vitamins, protein and minerals. Essential nutrients are compounds that the body cannot make and must be obtained from the diet. They are vital for disease prevention, sustained growth and good health.

Many consumers do not realise that exposure of milk to light, including retail lighting systems, can have a detrimental effect on milk. Light from all sources including sunlight, refrigerator lighting and especially retail lighting display cases can accelerate the detrimental loss of nutrients from milk. The damaging effects of light can be influenced by the light intensity and time of exposure, so longer exposure to light causes milk to deteriorate faster. Understanding the process that causes the detrimental effects of light on milk means that steps can be taken to protect the delicate nutrients in the milk they purchase.

Glossary

AES	Accelerated *ex situ*
Ag	Silver
AIS	Accelerated *in situ*
AZC	Ammonium zirconium
B_2	Riboflavin
B_5	Pantothenic acid
B_6	Pyridoxine
B_9	Folic acid
B_{12}	Cobalamin
BMD	Bone mineral density
CVD	Cardiovascular disease
CLA	Conjugated linoleic acid
DRI	Dietary Reference Intake
FAD	Flavin adenine dinucleotide
FMN	Flavin mononucleotide
GC	Gas chromatography
g	Grams
g/d	Grams per day
HDPE	High-density polyethylene
HPLC	High performance liquid chromatography
IDF	International Dairy Federation
IGF	Insulin growth factor
LED	Light emitting diode
LDL	Low density lipoprotein
LDPE	Low-density polyethylene
LPF	Light protection factor
lx	Lux: SI derived unit of illuminance and luminous emittance
MAP	Modified atmosphere packaging
mL	Millilitres
MS	Mass spectrometry
MSA	Measurement system analysis
mg	Milligram
NIDDM	Non-insulin dependent diabetes mellitus
nm	Nanometres
nmol/L	Nanomoles per litre
PPC	Poly(propylene carbonate)
PPM	Parts per million
PET	Polyethylene terephthalate
PLA	Polylactic acid
PUFA	Polyunsaturated fatty acid
RDA	Recommended daily allowance
SFA	Saturated fatty acid
SNP	Single nucleotide polymorphism
TiO_2	Titanium dioxide
UHPH	Ultra-high-pressure homogenisation
UHT	Ultra-high temperature processing
UVS	Ultraviolet-visible spectrometry
µg	Microgram
λ	Wavelength

1.0 Introduction

On a global scale, the top ten countries produce some 356.2 billion litres of fluid milk annually[1]. The UK is a significant global producer, with about 1.8 million cows producing on average 500 – 600 million litres of milk per month[2], making the UK the tenth largest global milk producing country[3]. Liquid milk makes up the majority of dairy product manufacture with an approximate total of 2.3 billion litres produced in the UK per year[4].

For many people, a healthy and well-balanced diet includes foods from all the food groups. The dairy group is especially important for children and adolescents because of the high amounts of protein, calcium and vitamins that are used to build strong bones and reduce the risk of chronic diseases later in life[5, 6]. Health professionals recommend that children over 12 months drink approximately 240 - 360 mL of whole cow's milk per day, rising to 500 mL per day after 2 years of age[5, 7]. Two to three glasses (120 mL per glass) help provide a high proportion of protein and other essential nutrients and vitamins to keep an adult healthy and reduce the risk of developing a range of diseases and developmental disorders. In order to digest milk, the enzyme lactase is required[8-10] and the prevalence of high lactase activity levels in adulthood is most common among people of Northern European countries, where the climate is conducive to dairy farming. Consequently, milk and dairy products have been part of the adult daily diet in Northern European populations for centuries The key nutrients in milk and their contribution to health are shown in Table 1.

Table 1: Nutrient Composition of Milk (RAW DATA)

Essential Nutrient[2]	Why the body requires this nutrient	Percentage of RDA in 1 glass of milk[3] (120mL)
Calcium	Maintains strong teeth and bones	27.6
Protein	Builds muscle and maintains strength	45.0
Vitamin B_2 (Riboflavin)	Turns carbohydrates, fats and protein into fuel for the body	34.4
Vitamin B_3 (Niacin)	Maintains and controls energy	1.6
Vitamin B_5 (Pantothenic acid)	Helps optimise protein, fats and carbohydrates	17.7
Vitamin B_{12} (Cobalamin)	Helps blood cells and nervous system development	44.6
Vitamin A	Maintains growth and keeps eyes and skin healthy	7.6
Vitamin D_2	The sunshine vitamin: Helps maintain teeth and bones	49.0
Magnesium	Controls how your muscles and nerves work. It helps to keep your bones strong, heart healthy and blood sugar levels normal	6.0
Potassium	Regulate fluid balance, muscle contractions and helps nerve signals	7.4
Phosphorus	Works with calcium to help build strong bones. Helps the body's energy production and maintains cell membranes	31.7
Zinc	Helps the immune system fight off invading bacteria and viruses. Needed to grow and develop properly. Also helps wounds heal and is important for senses of taste and smell.	8.9
Vitamin B_1 (Thiamine)	Essential to aid glucose metabolism; plays a key role in nerve, muscle and heart function	9.0
Vitamin C (Ascorbic acid)	Essential for nerves and protein metabolism and wound healing	0.6
Vitamin E (Tocopherol)	Supports immune function and eye health, prevents inflammation	1.0
Vitamin B_9 (Folate)	Essential to maintain DNA and metabolise amino acids	3.0
Selenium	Protects cells from damage, protects against cancer and heart disease. Required for thyroid function	16.4
Milk also contains all the essential amino acids required for optimum growth		
RDA: Recommended Daily Allowance		

1.0 Introduction

1.1 Consumption data

Consumption data indicates that on average adults over 18 years of age in the UK drink approximately 1.45 litres of milk a week[11]. For the over 60 age group it is important to maintain this level of milk consumption to support bone health as milk contains calcium (125mg per 100 mL) that contributes 12% of the recommended daily allowance (RDA)[12]

The most recent scientific evidence supports the consumption of cow's milk across the age spectrum as part of a healthy diet[13]. Milk contributes essential macro- and micronutrients, including vitamins A and D, that aids growth during rapid development in early childhood[7].

As milk and milk products are important sources of many essential nutrients, such as protein, calcium and riboflavin (Vitamin B_2), avoidance of dairy products is not advised without a confirmed diagnosis of lactose intolerance[8].

The majority of milk sold commercially undergoes some form of processing, usually pasteurisation to reduce the microbial load and make milk safe for human consumption. The effects of heat processing and shelf-life storage on water-soluble vitamins in milk have been well-documented[14-17]. Vitamin C is particularly prone to degradation during processing because of its high susceptibility to oxidation in the presence of oxygen and metal ions, as well as degradation during heat treatment[15]. Riboflavin (vitamin B_2), is very sensitive to light and UV radiation but relatively stable to heat and atmospheric oxygen[18]. Losses in vitamin C, folate (vitamin B_9) and cobalamin (vitamin B_{12}), increase with higher processing temperatures and sterilization which can cause significant losses of all vitamins and additionally cause protein degradation.

1.2 Health benefits of dairy

Good nutrition and access to an adequate diet and health are essential for child growth and development, including bone strength throughout the life span. Adequate nutrition is crucial in childhood development as good nutrition affects their health, cognitive performance and their economic status in adulthood[13].

While undernourishment has been declining globally, there have also been improvements in child nutritional status as expressed by the key measurements of child development, being underweight, wasting and nutrition-related child mortality. Access to better and more diversified diets is the key to combat problems of micronutrient malnutrition or "hidden hunger"[19]. Despite progress in addressing micronutrient malnutrition in some countries and regions, several billion adults and children across the world continue to be affected by one or more micronutrient deficiencies[13]. Micronutrient deficiency is still of concern as it is estimated that many people do not have sufficient levels of essential micronutrients such as zinc, folate (vitamin B_9) and cobalamin (vitamin B_{12})[20].

Milk contains a wide range of essential nutrients and it can make a significant contribution to meeting the body's needs for calcium, magnesium, selenium, riboflavin (vitamin B_2), cobalamin (vitamin B_{12}) and pantothenic acid (vitamin B_5). However, milk does not contain enough iron or folate (vitamin B_9) to meet the needs of growing infants and the low iron content is one reason animal milks are not recommended for infants younger than 12 months of age. Milk and dairy products play a key role in healthy human nutrition and development throughout life and especially in childhood. It is important to remember that milk is a natural source of bioactive fatty acids. In addition to being a source of concentrated energy, they serve as an important delivery medium for fat-soluble vitamins (such as vitamin D and E) and contain various fatty acids (e.g. conjugated linoleic acid (CLA)) and bioactive factors beneficial to health (e.g. triacylglycerols and phospholipids), which have a wide range of beneficial actions[21, 22]. An overview of the benefits and risks of dairy milk is shown in Table 2

Table 2: Health benefits and risks of Milk Consumption

Benefits:	Risks:
Milk and dairy are a source of energy and high-quality protein and make a significant contribution to requirements for calcium, magnesium, selenium, riboflavin B_2, cobalamin (vitamin B_{12}) and pantothenic acid (B_5) in the diet.	Cow's milk does not contain appreciable amounts of iron and presents a high renal solute load to infants compared with breast milk, due to its higher contents of minerals and protein. According to FAO guidelines[13], no undiluted cow milk should be given to infants younger than 12 months of age unless accompanied by iron supplements, although cheese and yoghurt may be given after 6 months.
Cow's milk is associated with increased growth and can help prevent developmental problems, especially during the first 2 years of life[149]. In children with poor nutritional status, milk is likely to supply nutrients that are important for growth and are deficient in the diet, while in well-nourished children the effect of milk on linear growth is likely.	Greater adult stature is not always associated with better health. The factors that lead to greater adult attained height, or its consequences, increase the risk of cancers of the colorectum and breast (post-menopause). Height is also generally accepted to be a risk factor for increased osteoporotic fractures.
Dietary fat from milk is important in the diets of infants and young children and especially in populations with a very low-fat intake. May help in the treatment of undernutrition.	About 60% of milk fat consists of saturated fatty acids (SFAs), including lauric acid, myristic acid and palmitic acid. Milk is a major contributor to ruminant trans fatty acid in the diet.
Milk contains calcium and protein, important for bone health[150] and dairy products also provide other nutrients that support bone health, such as potassium, zinc, vitamin A and vitamin D.	Calcium requirements vary depending on dietary factors such as intake of vitamin D, animal source proteins, sodium and other factors such as physical activity and sun exposure. This may explain the "calcium paradox"[147], and includes hip fracture rates that are reportedly higher in developed countries where calcium intake is higher than in developing countries where calcium intake is lower[148].
The impact of dietary dairy products on bone health depends on life stage. Milk consumption in childhood may protect against the risk of osteoporotic fractures in postmenopausal women later in life. For older people in countries with high fracture risk, there is convincing evidence for a reduction in risk of osteoporotic fracture with sufficient intake of vitamin D and calcium together, especially in people who have very low intakes of calcium, vitamin D or both.	Milk consumption during adult life is recommended to improve bone health and is associated with a reduced risk of fracture. Dairy can reduce the risk of calcium-deficiency rickets.
Observational evidence does not support the hypothesis that dairy fat contributes to obesity. There may be a protective effect of milk and dairy on weight due to components such as protein.	Dairy is a dense energy source and energy balance is critical to maintaining healthy body weight. Cross-sectional epidemiological studies indicate that high dairy food intake can contribute to weight management.

1.0 Introduction

Benefits:	**Risks:**
There is moderate evidence showing an association between milk and dairy product consumption and lower incidence of NIDDM in adults. Some studies suggest that dairy food consumption may have a beneficial impact on some metabolic syndrome components.	There is limited evidence demonstrating that milk and dairy product consumption is associated with the reduced risk of metabolic syndrome.
Although dairy foods contribute to SFA content of the diet, other components in milk such as calcium and PUFAs may reduce risk factors for CVD. The majority of review studies conducting meta-analyses of prospective studies conclude that low-fat milk and total dairy product consumption is generally not associated with CVD risk and may actually contribute to a reduction of CVD.	Dairy products contain SFAs. SFAs may increase LDL cholesterol and risk of CVD. Industrial trans fatty acids are associated with an increased risk of CHD. The evidence regarding ruminant trans fats and CVD risk is inconclusive.
Some components in milk and dairy products such as calcium, vitamin D, sphingolipids, butyric acid and milk proteins may be protective against cancer. Milk and calcium probably protect against colorectal cancer.	Childhood milk consumption may have positive mitigating effect on subsequent cancers in adulthood. Although, diets high in calcium and high consumption of milk in later years may be a factor in the development of prostate cancer.

Key: CVD – cardiovascular disease; CMA – cow-milk allergy; LDL – low-density lipoprotein; PUFAs – polyunsaturated fatty acids; SFA – saturated fatty acid; NIDDM – non-insulin dependent type 2 diabetes mellitus.

2.0 Aim of Report

The aim of this study is to collect, review and summarise the scientific findings from published literature on the detrimental effects of light on milk. Additionally, the focus of the report is on the detrimental effect on micro- and macronutrients and factors affecting consumer acceptance of milk

This report focuses on the role of dairy milk in human nutrition, health and development. It takes a broad view of dairy and the consumer and explores the linkages between dairy, development, human nutrition and health. Milk is a source of essential nutrients including vitamins and minerals and is a complex food source with multiple benefits across the age span. As such, milk may be considered as a complex functional food, as it is known to have a beneficial effect on one or more target functions in the body that go beyond nutritional effects[23].

The objective of this review is to raise awareness of the negative effects of light on the nutritional properties of milk. This awareness of damage from light will aid manufacturers of milk containers and also retailers of milk to ensure that effective light protective materials are used so that the nutritional benefits are retained, and that consumer satisfaction is maintained.

3.0 Approach and Methodology

A scientific literature search was carried out using Web of Science, PubMed, Google Scholar and Scopus. Search results were refined using Boolean operators and results were manually evaluated to remove multiple and duplicate references. Search results were further refined for relevance. Results excluded other milk-based products such as cheese and yoghurts.

Keywords and phrases used in the search are listed in Appendix 1.

A further search was carried out through grey literature sources. Grey literature is defined as:

"That which is produced on all levels of government, academics, business and industry in print and electronic formats, but which is not controlled by commercial publishers."[24].

In general, grey literature publications are non-conventional and sometimes transient publications. They may include but are not limited to the following types of materials: reports pre-prints, preliminary progress and advanced reports, technical reports, statistical reports, memoranda, state-of-the art reports, market research reports, theses, conference proceedings, technical specifications and standards, technical and commercial documentation and official documents not published commercially.

Links to grey literature websites are listed in Appendix 1

4.0 Literature Review Findings

The health effects of nutrient loss in milk are reported with a proposed strategy for the adoption of light protective packaging materials that are certified for light protection. Published literature has been reviewed with an emphasis on recent publications from 2015-2019. The date range was chosen specifically to review new developments in packaging technology.

Literature search results revealed a considerable number of published papers from both scientific and grey literature sources. After refinement of search terms, the most recent information was analysed for new technological developments aimed at the protection of milk from the effects of damaging light. Total publications that refer to light degradation of nutrients in fluid milk by decade are shown in Figure 1.

Analysis of grey literature showed that there was considerable duplication of results and after re-processing the data, a file was generated with 697 relevant results for light degradation of nutrients in milk. Publications in peer reviewed journals were excluded from the grey literature search as they appear in the main literature report. The total number of reports that refer to light degradation of nutrients in fluid milk are shown in Figure 2

Figure 1: Number of scientific publications by decade from 1901 to 2019. Note that 1901-1910 = 2 peer reviewed publications and 1911-1920 = 6 peer reviewed publications.

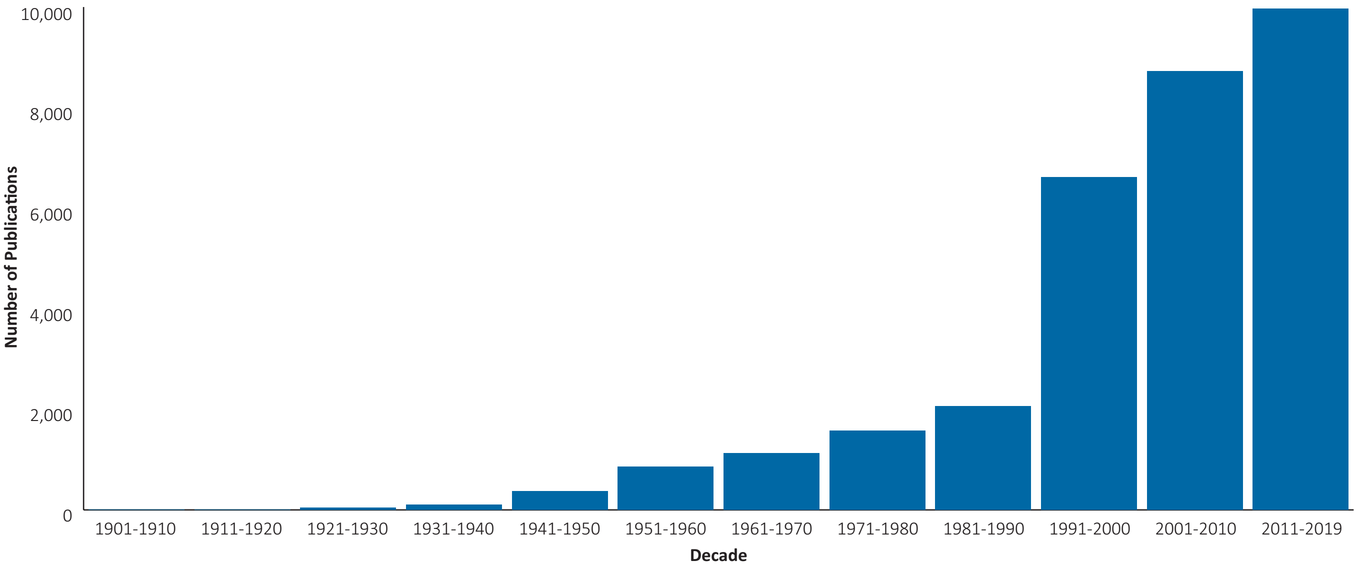
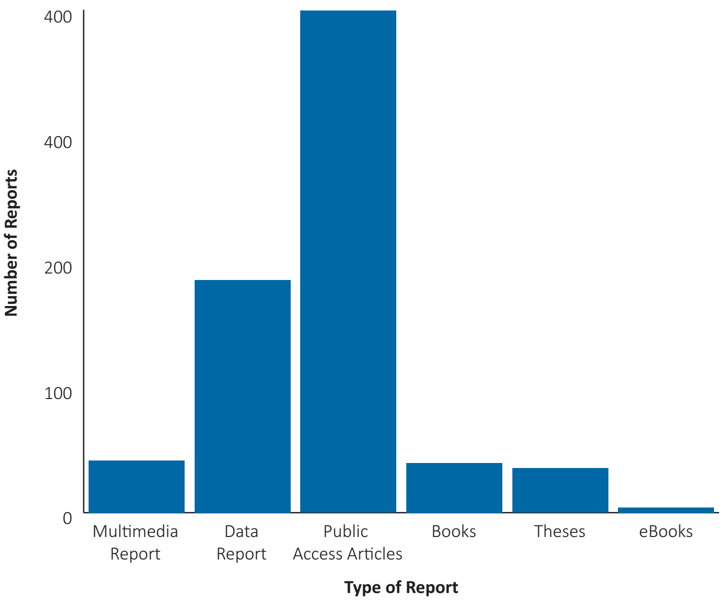


Figure 2: Number of relevant reports from Grey literature 2015-2019.



5.0 Health Effects of Essential Nutrients Derived from Milk

Although research on nutrition has traditionally focused on identifying the specific mechanisms and health impacts of single nutrients, the constituents of milk or other dairy foods interact to produce beneficial outcomes. The nutritional value of dairy products should not be considered as equivalent to their nutrient contents but on the basis of the biofunctionality of the nutrients within dairy food structures and how these components interact with each other. The International Dairy Federation (IDF) strategy supports dairy's contribution towards improving the health of all age groups through the nutrient density of milk and the impact of the dairy matrix[25].

Numerous scientific studies have supported the essential role of milk and dairy products as part of a balanced diet and according to recommended daily allowance for essential nutrients, which is linked to a variety of beneficial health effects. A number of recent systematic reviews as discussed below, indicate that increased dairy consumption may protect against cardiovascular disease, weight gain and obesity and may also significantly reduce the risk of type 2 diabetes and vascular diseases such as stroke, despite the fat or saturated fat content of milk.

5.1 Cardiovascular disease

Increasing research evidence suppxorts the crucial function of nutrition in the development xq of chronic diseases such as cardiovascular disease (CVD), cancer, insulin-resistance and obesity[26]. However, in the public domain people view dairy fat as a negative component of milk and dairy products, generally because they are energy-dense and relatively high in cholesterol and saturated fat. Dairy products are conventionally viewed as having an adverse effect on health particularly in relation to CVD, which is a leading cause of death in the developed world, due to a wide range of lifestyle factors including diet, stress, obesity, sedentary lifestyle, type 2 diabetes and smoking. Lordan and colleagues (2017), in their review discussed the nutritional value of the lipid components in milk and dairy products with a view to suggesting that milk lipids show anti-inflammatory activities. An inflammatory response is a necessary process of the innate immune system and is required for physiological responses such as initiating tissue repair and eliminating pathogenic bacterial attack, but an uncontrolled inflammatory response can lead to tissue injury[27]. This uncontrolled inflammatory response is an integral feature of atherosclerosis, CVD, cancer, type 2 diabetes, obesity and Alzheimer's disease and many age-related disease states[28-31].

Recommended Daily Allowances (RDAs)

The dietary reference intake (DRI) is a system of nutrition recommendations that advises on the required dietary intake level considered sufficient to maintain good health. The amount of each nutrient needed is called the nutritional requirement. Individual requirements of each nutrient are related to a person's age, gender, level of physical activity, growth stage and overall state of health.

RDAs were developed by the Committee on Medical Aspects of Food and Nutrition Policy and are regularly revised based on the latest research recommendations. RDAs have been set for a range of nutrients including:

- **Protein**
- **Vitamins: Thiamine (vitamin B_1), riboflavin (vitamin B_2), niacin (vitamin B_3), pyridoxine (vitamin B_6), folate (vitamin B_9), cobalamin (vitamin B_{12}), vitamin C, vitamin A and vitamin D**
- **Minerals: Calcium, phosphorus, magnesium, sodium, potassium, chloride, iron, zinc, copper, selenium and iodine**

Soedamah-Muthu & Sabita (2018), reviewed both beneficial and detrimental nutrients in relation to cardiometabolic diseases[32]. Their study concluded that an intake of total dairy or low-fat dairy (200 g/d) was inversely associated with a 3 - 4% lower risk of diabetes. Furthermore, total dairy and milk were not associated with an increased risk of cardiovascular disease. An additional 200 g of dairy milk intake per day was also associated with an 8% lower risk of stroke. Diez-Fernández *et al* (2019), conducted a review to determine the relationship between dairy consumption and arterial stiffness as a measure of cardiovascular risk[33]. Their review examined studies in a meta-analysis, with a total of 16,443 patients. Milk intake showed no significant association with increased arterial stiffness. Due to the scarcity of studies, further investigations are warranted to clarify the role of dairy products on arterial stiffness.

5.2 Bone health

Osteoporosis is a major public health problem affecting over 200 million people worldwide and is increasing within ageing populations[34-37]. Low bone mineral density (BMD) and osteoporosis-related fractures constitute a considerable public health burden worldwide. Dairy foods such as milk, cheese and yogurt provide a unique set of nutrients, such as calcium, protein, vitamin D (D_2 and D_3 fractions), magnesium and potassium, which are thought to be beneficial for bone health[38].

Rizzoli *et al* (2018), undertook a meta-analysis that addressed the risks and benefits of dietary protein intake for bone health in adults. This study suggested that dietary protein levels above the current RDA may be beneficial in reducing bone loss and hip fracture risk, provided that calcium intake is maintained[39]. It was further determined that higher than RDA levels of protein may be associated with higher bone density and may beneficially attenuate bone loss in osteoporosis by reducing bone turnover. Higher levels of protein can be obtained from increased daily milk consumption. The conclusion of this study suggests that long-term, well-controlled randomized trials are required to further assess the influence of dietary protein intakes on fracture risk. A further study on bone mass levels was undertaken by Bian and co-workers (2018), that indicated that consumption of dairy, yogurt and cheese was associated with lower risk of hip fracture in cohort studies. However, there was insufficient evidence to determine the relationship between milk consumption and risk of hip fracture[40]. A lower threshold of 200 g/d milk intake was suggested to have beneficial effects, whereas the effects of a higher threshold of milk intake were unclear.

Rouf and colleagues (2018), asserted that calcium and dairy products have a role in the prevention of chronic diseases and achievement of peak bone mass, especially during adolescence. However, intakes were often suboptimal and interventions to improve consumption of dairy sources were suggested as a positive intervention strategy[41]. Their systematic review aimed at investigating the efficacy of intervention regimes promoting calcium or dairy foods among young adults. The review concluded that adolescents (age 19.9 ± 1.4 years) were responsive to intervention studies. Fabiani and co-workers (2019), reviewed a range of studies that examined the association between diet and bone health[42]. From studies that observed fracture rates, adherence to increased dairy in diets reduced the risk of fracture particularly in elderly women.

van Dongen and co-workers (2019), suggested that there is strong evidence for a positive association between milk and bone mineral density, although there was limited evidence for yogurt intake[38]. Vitamin D is involved in calcium homeostasis, suggesting that both suitable levels of calcium and vitamin D are needed to ensure optimal calcium absorption. Results from the Framingham Study[43] have demonstrated that a higher intake of dairy foods (milk, milk + yogurt and milk + yogurt + cheese) was protective against bone loss among vitamin D supplement users. This suggests that adequate vitamin D levels may provide bone-protective benefits with higher dairy intakes. The review suggested that future studies of dairy products should focus on novel measures of bone density and an association of specific dairy foods that should also consider vitamin D status.

Overall, the consumption of high calcium, high protein dairy foods in the diet is advocated for bone health across the lifespan to reduce the incidence of fracture. However, to date the efficacy has not been fully demonstrated, which indicates that further studies should be conducted as inferred from cross-sectional and prospective studies[44].

5.0 Health Effects of Essential Nutrients Derived from Milk

Benefits of Milk in Children's Diet

- Children who are exposed to highly allergenic foods (milk, peanuts, eggs, wheat, etc.) earlier in life have a lower risk of developing a food allergy later in life[151]
- Children build 40% of their bone mass between the ages of 9 – 14 and 90% of their bone mass by their late teens. Dairy products contain all of the crucial vitamins and minerals used for this process[150]
- Dairy products have characteristics that protect the enamel of children's teeth, creating stronger teeth and a healthier mouth
- Milk provides higher amounts of protein, calcium and potassium per calorie than any other commonly consumed food. For example, for a child aged 4 – 8 years, an 240mL glass of milk provides 40% of their daily protein needs and 50 – 60% of their daily calcium requirements
- Milk also provides a wide range of micronutrients, such as minerals as well as a being a source of essential vitamins and protein

5.3 Type 2 diabetes

Dairy product intake has been as inversely associated with a risk of non-insulin dependent type 2 diabetes (NIDDM) in numerous cohort studies, although the beneficial effects of increased diary intake remain inconclusive in clinical trials[45]. A recent study by Vissers *et al* (2019), investigated if there was a causal association between the intake of dairy products and the incidence of NIDDM. However, their study using genetic analysis for specific single nucleotide polymorphisms (SNPs) for lactase persistence was inconclusive for an increased risk factor for NIDDM[46].

6.0 Effects of Light Exposure on Milk Flavour

The detrimental effect of light on milk nutrients has been known for over 100 years with an early publication by Kinsella in 1906, entitled 'Care and Treatment of Milk', in which the author identified two different flavours in milk; classed as 'fresh' or 'contaminated'[47]. Since then there has been a growing interest in this area of research with a concomitant rise in published literature as shown in Figure 1.

Initially, considerable work was focused on the degradation of a range of essential nutrients. However, more recently the research has changed focus to examine the effects of protective technological developments that help in the preservation of these essential nutrients in milk.

Milk takes on a distinctive off-flavour when exposed to light and this is often referred to as 'sunlight flavour' which is detrimental to milk consumption[18, 48, 49]. The mechanism for this distinct change in organoleptic quality has most often been assumed to be because of riboflavin degradation[50]. However, Wold and co-workers (2015), asserted that riboflavin initiates the oxidative process as riboflavin and beta-carotene, a terpenoid, are the most prominent light absorbers in milk. When exposed to violet and blue light, significant changes were noted, on exposure to orange and red light it was determined that a stronger off-flavour through generation of damaging oxygen radicals occurred[51]. The photosensitising process is activated in the presence of chromophores such as chlorophylls and porphyrins to produce oxygen radicals. These activated oxygen species that can cause damage to milk nutrients and lead to undesirable changes in milk include; singlet oxygen; hydroxyl radicals; ozone and superoxide anions[52, 53]. Milk contains chlorophyll compounds at very low levels, derived from the grass diet of cows and these are particularly sensitive to violet, orange and red light. Chlorophyll compounds have until recently been very difficult to detect in milk but advanced analytical techniques are now able to detect these compounds, additionally trained sensory panels can detect the oxidised flavour compounds of chlorophylls within 25 min[51]. These photosensitisers are degraded as a function of wavelength, oxygen level and time[54] and have been identified as:

– Riboflavin

– Protoporphyrin

– Hematoporphyrin

– Tetrapyrroles (such as vitamin B_{12})

Off-Flavours in Milk

Milk of good quality is bland with a slight sweet taste, very little odour and a smooth feel in the mouth with very little aftertaste, although this taste profile can be subjective.

Off-flavours in milk are often described as rancid or oxidised, the term 'sunlight flavour' is also used when milk has been exposed to strong light. Light activated flavour results from chemical changes in proteins and vitamins and this can increase with light intensity and duration of light exposure[152]. Light of short wavelength (blue and green) has a stronger effect than longer wavelengths of light (yellow and red). Shorter wavelengths of light emitted by fluorescence or LED lighting systems do not give off heat and this is why milk in retail settings is often displayed under this type of light. Light sensitive vitamins can be rapidly degraded under intense light, especially riboflavin (vitamin B_2) and vitamin A, causing a chemical reaction that leads to detrimental flavour changes[61]. Exposure to light for as little as 25 minutes can cause a distinct flavour change. Prevention of these flavour changes simply involves protecting milk from exposure to light from all sources.

6.0 Effects of Light Exposure on Milk Flavour

In particular the tetrapyrrole chromophores are of interest and are a class of molecules that add colour and are the most abundant pigments found in nature. Organisms synthesize tetrapyrroles either *de novo* (the most abundant being usually heme and chlorophyll) or have to derive them from their diet[55]. They are essential for the synthesis of chlorophylls and perform diverse biochemical functions. These panchromatic absorbers perform across the light spectrum, displaying a profound shift of absorption intensity from the strong violet-blue bands (Soret band) of typical porphyrins into the green, red and near infra-red spectrum (λ 400 – 720nm)[56-58].

6.1 Source of light exposure

Light exposure through all sources has a detrimental effect on milk. Natural daylight has been shown to have a damaging effect within a very short time frame[59], this can be detected by sensory analysis with a 25 minute time frame. In a retail setting, LED and fluorescence light sources are most commonly used to display milk. Wang and colleagues (2018), found that exposure to LED lighting systems with a low intensity of 1068 lx caused degradation of a range of essential nutrients in milk within 4 hr, higher intensity light (>4094 lx) combined with longer exposure time rapidly increased the oxidation processes[60]. This light degradation of essential nutrients is not only a function of light wavelength but also includes exposure time and light intensity.

6.2 Flavour compounds in milk caused by photooxidation

Photooxidation is a reaction caused by light which can lead to the generation of highly reactive free radical species of oxygen, which is frequently detrimental to the light exposed product. Understanding flavour compounds in milk is crucial when considering the changes that occur when milk is exposed to light. The ‘sunlight flavour’ that develops in milk is due to photooxidation reactions to compounds in the milk leading to the formation of volatile complexes through the breakdown of pigments and vitamins. These complexes originate from the degradation of lactose, citrate, lipids and milk proteins that cause biochemical changes[61]. See table 3 for a list of volatile compounds identified in milk.

Table 3: Volatile flavour compounds in milk caused by photooxidation

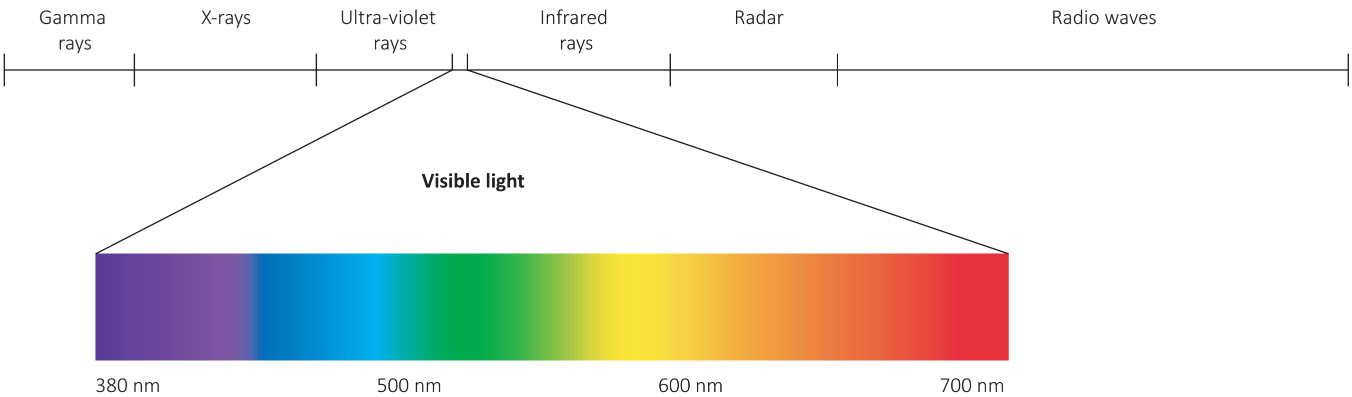
Description of off-flavour:	Volatile compound:
Oxidised	Heptanal, octanal, nonanal, 2-octenal, 2-nonenal, aldehydes
Malty	2/3-methylbutanal
Metallic	1-octen-3-one
Fruity	Ethyl butanoate, ethyl hexanoate
Degradation of amino acids (known as biochemical flavour)	Aldehydes, methanethiol, carboxylic acids

What is Light?

The electromagnetic spectrum is the entire range of wavelengths of all known electromagnetic radiation. This includes gamma rays, X-rays, microwaves, ultraviolet radiation, visible light, infrared radiation and radio waves.

The visible portion of light is a region of the electromagnetic spectrum which the human eye sees as a rainbow of colour. Generally, the human eye can detect wavelengths from 380 – 700 nanometres[153].

White light is a mixture of 7 colours: Red; orange, yellow, green, blue, indigo and violet. Each colour has a different wavelength with red as the longest wavelength and violet as the shortest wavelength. When all the colours are mixed together they make white light. The eye and the brain work together to convert visible light into an electrical impulse that is interpreted as an image that we see. The unit of light intensity is known as the lux (symbol lux or lx) and is a measurement of strength of the light shining on to an object (illuminance).



Groups of Individuals at Risk for Low Riboflavin Intake[154]

Pregnant/lactating women and infants

- **Pregnancy demands higher riboflavin intake as it crosses the placenta to help with foetal growth, if maternal status is poor during gestation, the infant is likely to be born riboflavin deficient**

Schoolchildren

- **Riboflavin deficiency among children is demonstrated in many regions of the world where they are deprived of adequate milk in their diet. Riboflavin deficiency among children in the Western world seems to be largely confined to adolescents, especially girls, because of increased metabolic demand and decreased consumption of milk**

The elderly

- **There is an increasing requirement of riboflavin with advancing age as a result of decreased efficiency of its absorption by enterocytes in the gut. In general absorption of the B group of vitamins decreases with age due in part to stomach lining atrophy. As the B group of vitamins act together, especially B_6, B_9 and B_{12}, it is important to maintain adequate intake to maintain health**

Eating disorders

- **Young women practicing unconventional eating habits accompanied by excessive exercise regimes in order to lose weight, have been shown to have low levels of riboflavin**

Neonates undergoing phototherapy

- **Hyperbilirubinemia in the neonatal period is often managed with phototherapy. However, it has been shown to degrade riboflavin and cause a deficiency in new-borns**

6.3 Sensory effects in milk caused by light damage

An early study by Chapman and co-workers (1998), examined 2% (Semi-skimmed) milk in high-density polyethylene (HDPE) containers after exposure to fluorescence light. Samples were evaluated by 10 trained panellists and by 94 consumers to assess the presence and intensity of sensory differences from unexposed control samples. Trained panellists detected flavour defects after 15 to 30 minutes of light exposure; consumers detected defects between 54 minutes and 2 hours. As approximately 50% of milk containers remain in dairy cases for at least 8 hours, these results suggest that a significant proportion of milk on retail shelves in containers without light protection are vulnerable to the development of detectable light-oxidized flavour defects[62].

6.4 Light activated flavour compounds

Jung and co-workers in 1998, showed that light-induced off-flavours and dimethyl disulfide increased significantly as fluorescence light exposure time was incrementally increased from 0 to 8 hours. Sensory evaluation and gas chromatographic (GC) analysis identified compounds suggesting that dimethyl disulfide was mainly responsible for the light-induced off-flavour in skimmed milk. Dimethyl disulfide was proposed to be formed by the singlet oxygen oxidation of methionine in milk. GC analysis and subsequent sensory evaluation showed that 200, 500, and 1000 ppm ascorbic acid, used as a singlet oxygen quencher when added to samples, lowered the formation of dimethyl disulfide and off-flavour in skim milk[63].

6.5 Vitamin B_2 (Riboflavin)

Riboflavin or vitamin B_2 is part of the group of vitamins collectively known as the vitamin B complex and is a water-soluble vitamin. Milk and dairy products have very high riboflavin content; its intake makes it the greatest contributor of the vitamin in Western diets, making riboflavin deficiency uncommon in populations. However, in developed countries, there is an increased intake of semi-skimmed milk, that has a lower level of riboflavin content[64]. Milk stored in glass or plastic receptacles is susceptible to riboflavin degradation through light exposure of milk, through any source and is of particular concern when milk is exposed to fluorescence or LED light sources as the vitamin degradation is increased within a short time-frame. Riboflavin deficiency is uncommon for those in the population that have an adequate intake of milk in their diet. However, individuals following a diet scarce in milk and meat, which are the best sources of riboflavin, may be prone to riboflavin deficiency[64].

6.0 Effects of Light Exposure on Milk Flavour

Recommended Daily Allowance for Riboflavin (Vitamin B_2)

Riboflavin (Vitamin B_2) is one of eight B vitamins that are essential for human health. It can be found in grains, plants and dairy products. Riboflavin (B_2) is crucial for breaking down food components and absorbing other nutrients such as proteins, fats and carbohydrates. Riboflavin (B_2) is required daily as the body only stores small amounts. Recommended intakes are as follows:

- **Infants (Age: 0-12 months): 0.3 - 0.4 mg/d**
- **Children (Age 1-9 years): 0.5 - 0.6 mg/d**
- **Adolescents (Age 10-18 years): 0.9 - 1.3 mg/d**
- **Adults (Age 19-70 years): Women: 0.9 - 1.1 mg/dl and Men: 1.1 - 1.3 mg/d**

Riboflavin is involved in the metabolism of macronutrients as well as the production of some other B complex vitamins. It is known to participate in redox reactions in the metabolic pathways through cofactors flavin adenine dinucleotide (FAD) and flavin mononucleotide (FMN), derived from riboflavin, by acting as an electron carrier[65]. Inadequate intake of riboflavin would be expected to lead to a disturbance in the intermediate steps of metabolism[66]. It is also known for its role as an antioxidant due to its involvement in the regeneration of glutathione, a free radical scavenger.

In addition, it is involved in growth and development, especially during foetal development, reproduction and lactation. Riboflavin is not stored in large amounts in the body; only small reserves exist in the liver, heart and kidneys. Most people obtain riboflavin from their diet. There are many individuals on restricted diet plans and many who do not consume dairy; these individuals are prone to developing riboflavin deficiency[67].

In 2009 Webster *et al* published research on blocking the excitation wavelength of riboflavin (absorption λ400; 446; 459; 570nm), using an overwrap of iridescent film on glass bottles containing milk[68]. The milk was then exposed to fluorescence lighting at 4 °C for up to 21 days and evaluated for light-oxidized flavour. A trained sensory panel evaluated the flavour and found that the overwraps limited the production of light-induced flavour changes. Analysis of volatile compounds determined that the production of pentanal and hexanal (the main degradation products of riboflavin) were reduced.

Wold *et al* (2005) in a study of cheese found that porphyrins and chlorins play an important role in the photooxidation of cheese. When stored in plastic films of differing colours analysis and sensory attributes had a significant outcome on oxidation processes[69]. Violet and blue films increased the characteristics of oxidised odour, sun flavour and acidity, whereas green, orange, yellow or red films showed a reduction in oxidised flavour compounds. The authors suggested that the breakdown of these tetrapyrroles, such as porphyrins and chlorins, contributed to photooxidation processes in cheese and other dairy products.

Sharabi *et al* (2018) found changes in the stability of riboflavin in milk when subjected to ultra-high-pressure homogenisation (UHPH) with up to a 50% loss of riboflavin due to indirect light scattering and subsequent absorbance of light at wavelengths related to the riboflavin oxidation wavelength[15]. The authors recommended that further research is carried out to gain a fundamental understanding of novel processing technologies on milk quality and nutritional parameters prior to adoption by industry.

6.6 Vitamin D

Vitamin D is a fat-soluble vitamin that promotes the absorption of calcium, regulates bone growth, improves neurological function and in part regulates the immune system[70]. The vitamin has two main forms ergocalciferol (vitamin D_2) and cholecalciferol (vitamin D_3)[71]. In general, it is recommended that adequate levels of vitamin D_3, are maintained as this is the most biologically active form of the vitamin[72].

A study in 2018 by Mahmoodani and co-workers, found that vitamin D_3 fortified milk declined in nutrients under storage conditions[73] and analysis by mass spectrometry (MS) techniques confirmed fatty acid lipoxidation as the likely cause. A recent study by Syama *et al* (2019) indicated that milk protein-vitamin complexation increases the stability of vitamin D_2 when exposed to light intensities of 1485, 2970 and 4455 lx. This observation of protein-vitamin complexation and its stability agree with an earlier study by Kaushik in 2014, that showed that vitamin D_2 remained stable in milk when stored in glass but not in containers manufactured from LDPE. The mechanism was proposed as sorption of vitamin D_2 onto the surface of LDPE[74]. The greatest loss of vitamin D_2 was shown when milk was exposed to white light at 2260 lx, thought to be due to the generation of singlet oxygen that was possibly related to the increase in photo-sensitizers from the degradation of riboflavin[18].

However, a recently published study by Schiano *et al* in 2019 indicated very limited loss of vitamin D_3 in vitamin fortified skimmed milk exposed to either fluorescence or LED light exposure at 2000 lx, which is in contrast to other published studies[75].

6.7 Vitamin D and Calcium

Calcium and vitamin D are interdependent in the human body, when the level of ionized calcium in the blood falls, parathyroid hormone is secreted by the parathyroid gland, stimulating the conversion of vitamin D to its active form, calcitriol (1,25-dihydroxyvitamin D) and thus, depletes vitamin D status[76]. Vitamin D, as calcitriol, influences calcium absorption across the intestine and inadequate vitamin D status is associated with reduced absorption of calcium from the diet. Vitamin D is therefore critical for enhancing gastrointestinal calcium absorption and mineralisation of bone tissue[77].

Vitamin D can either be made in the skin from a cholesterol-like precursor (7-dehydrocholesterol)[78], by exposure to sunlight or can be provided preformed in the diet, especially from consumption of milk. The current recommended intake of dietary vitamin D ranges from 5 µg/d for infants, children, adolescents, adults aged 19–50 years and pregnant and lactating women to 15 µg/d for adults more than 65 years old[72], see Table 1 for recommended daily allowances (RDAs).

Vitamin D deficiency, when serum 25-hydroxyvitamin D is lower than 25 nmol/L, occurs in risk groups all over the world. For example, it is estimated that in the UK 1 in 5 people across all age groups, are deficient in this essential vitamin. Risk groups for poor vitamin D status are children especially those with low birth weight, adolescents, pregnant women, older persons and non-Western immigrants[79].

Clinical manifestations of vitamin D deficiency often present as rickets in children and osteomalacia in adults. In recent years, however, non-musculoskeletal conditions - including cancer, metabolic syndrome, infectious and autoimmune disorders, have also been found to be associated with low vitamin D levels. The spectrum of these common disorders is of particular concern because observational studies have demonstrated that vitamin D insufficiency is widespread in many northern regions of the world, including industrialised countries[80]. The increasing prevalence of disorders linked to vitamin D deficiency is reflected in the several hundred children with rickets treated each year in the UK[81].

However, these children represent a small proportion of the individuals with a suboptimal vitamin D status in the UK population. A recent nationwide survey in the UK showed that more than 50% of the adult population have insufficient levels of vitamin D and that 16% have severe deficiency during winter and spring[82].

Nutritional rickets remains a global public health problem, despite effective and inexpensive means to prevent and treat the disease. It is most prevalent in the infant/toddler age groups and the adolescent, but vitamin D deficiency is also prevalent in women of child bearing age, resulting in babies being born with low vitamin D stores and the mothers having inadequate vitamin D in breast milk, thus exacerbating the risk for rickets in these infants[81].

Vitamin D Deficiency

- **Vitamin D deficiency is common in the UK population[72]**
- **Vitamin D deficiency commonly presents with bone deformity (Rickets) or hypocalcaemia in infancy and childhood and with musculoskeletal pain and generalised weakness in adults**
- **Many other health problems (including cardiovascular disease, type 2 diabetes, some cancers and autoimmune conditions) have recently been associated with vitamin D deficiency[155]**
- **Risk factors include, skin pigmentation, use of sunscreen or concealing clothing, being elderly, malabsorption, renal or liver disease and anticonvulsant therapy**
- **Rickets and osteomalacia should be treated with high strength calciferol and regular vitamin D supplements[156]**

6.8 Protein

Protein comprises half of the volume of bone. Bone can be considered a composite material composed of a protein matrix, within which calcium (and other mineral) salts are deposited.

Many epidemiological studies have found a positive relationship between protein intake and bone mass or density, and some studies suggest an inverse association between protein intake and incidence of hip fracture in the elderly[39, 83, 84].

The protein in cow milk is of high-quality (defined as protein that supports maximal growth), containing a good balance of all the essential amino acids[85]. Calcium is essential for bone density and growth through the lifespan, cow's milk contains high levels of bioavailable calcium[86, 87].

The major proteins found in milk are casein and whey proteins, with casein (αs1-, αs2-, β- and κ-casein,) accounting for approximately 78 percent of the protein in cow's milk and whey proteins accounting for about 17 percent of the total protein[88, 89]. The main whey proteins are β-lactoglobulin, α-lactalbumin, serum albumin, immunoglobulins and glycomacropeptide; minor proteins include lactoferrin, insulin growth factor (IGF) and the lactoperoxidase system and these proteins vary according to the source of milk. Milk is considered to be an excellent source of essential amino acids for human nutrition, growth, and development[90].

Casein, the predominant milk-protein component, is widely accepted to be a valuable source of amino acids for human growth. Traditionally, whey was considered as a low-value by-product of cheese production, but in recent decades, whey components have attracted increasing commercial interest[88]. The whey fractions contain a variety of proteins which can be separated by processes such as ultrafiltration and reverse osmosis to produce whey-protein concentrates. Whey proteins, in addition to delivering amino acids, are reported to be involved in protection against infections, immune enhancement and development of the gut[91].

What is Protein?

Protein is a macronutrient that is essential to building muscle mass and makes up approximately 15% of body weight[49].

Protein is composed of amino acids which are organic compounds that form the building blocks of proteins. Many amino acids are essential and can only be derived from the diet. The body uses protein to build and repair tissues, additionally protein contributes to the production of enzymes, hormones, bones, cartilage and skin[90].

Protein requirements vary dependent on age, gender and activity levels, generally 0.8 grams of protein per kilogram of body weight is recommended per day. Protein foods that contain all the essential amino acids are known as complete proteins and are usually derived from animal protein and milk sources[157].

Proteins in milk can be degraded by enzymatic action or by exposure to light sources. The predominant cause of protein degradation is through enzymes called proteases which are inherent in milk. Undesirable degradation known as proteolysis, results in milk with off-flavours and is of poor quality. Two amino acids in milk, methionine and cystine are sensitive to light and may be degraded with exposure to light. This results in an off-flavour in the milk and loss of nutritional quality for these 2 amino acids[60].

Minerals in Milk

Minerals are usually inorganic substances and are needed in the diet to make body systems function properly. They are essential for building strong bones and teeth and for our metabolism that turns food into energy. Essential minerals include calcium, iron and potassium. A normal healthy and varied diet will supply all the minerals that are needed by the body, although some groups within the population may need supplements depending on age, gender or if they are pregnant.

The minerals in a 240mL serving of milk are listed below:

Mineral	Amount in 240mL of milk	Percentage (%) of RDI
Calcium	276mg	27.6
Copper	0.027mg	3.0
Iron	0.07mg	0.9
Magnesium	24mg	6.0
Manganese	0.007mg	0.3
Phosphorus	222mg	31.7
Potassium	349mg	7.4
Selenium	9µg	16.4
Sodium	98mg	6.5
Zinc	0.98mg	8.9

Values from British Nutrition Foundation (2019)

6.9 Minerals

Milk contains a wide range of minerals that are essential for maintenance of growth and development. Milk is a good source of calcium, magnesium, phosphorus, potassium, selenium and zinc. Many minerals in milk are associated together in the form of salts, such as calcium phosphate. In milk approximately 67% of the calcium, 35% of the magnesium and 44% of the phosphate are salts bound within the casein micelle and the remainder are soluble in the serum phase. The fact that calcium and phosphate are associated as salts bound with the protein does not affect the nutritional availability of either calcium or phosphate[86].

The characterisation of mineral composition was recently undertaken by Visentin and co-workers (2018). The results of their study compared trace minerals in cow's milk compared to levels in human milk as follows:[92]

The concentration of iron in cow's milk, 0.40 - 0.59 µg/ml, was found to be very similar to that of human milk, 0.20 - 0.69 µg/ml. The copper concentration of cow's milk (0.06 - 0.09 µg/ml) is lower than in human milk (0.24 - 0.50 µg/ml) whereas the concentration of zinc is higher in cow's milk (3.23 - 5.15 µg/ml) than in human milk (1.16 - 3.83 µg/ml). Cow's milk contains about 4 - 5 times more calcium and magnesium, 854 - 1430 µg/ml and 87 - 131 µg/ml, respectively, than human milk (220 - 252 µg/ml and 26 - 35 µg/ml). Cow's milk was further fractionated and the trace elements and mineral content of the different fractions were compared to results from human milk. Whey proteins bind a major part of these elements in human milk, but not in cow's milk. Significant amounts of iron are bound to the lipid fraction in both cow's and human milk (14 and 33%, respectively), predominantly bound to the outer fat globule membrane. Low molecular weight compounds (ligands), bind significant proportions of all the elements investigated in both cow's and human milk, with the exception of zinc in cow's milk, of which only 2% is associated with this fraction.

7.0 The Role of Packaging

Packaging provides essential protection from the environment and from chemical and physical challenges, thereby playing a crucial role in protecting the quality and safety of food and drink products[93-95]. The primary purpose of food and drink packaging is to maintain the safety, freshness and quality of the product[96]. The impact of packaging waste on the environment must be balanced with the avoidable volume of food and drink waste, that can be minimized by prudently selecting materials that contribute to extended shelf-life of products and help to reduce environmental impact[97-99].

7.1 Materials Used in Food & Drink Packaging

Package design and construction play a significant role in determining the shelf life of a food product[96, 97, 100, 101]. The right selection of packaging materials and technologies maintains product quality and freshness during distribution and storage[102, 103].

7.2 Packaging materials

There are several advantages to using polymer materials for food packaging. Packaging production processes transform polymers into a wide range of shapes and structures, offering considerable design flexibility[104, 105]. These polymers are inexpensive and lightweight with a wide range of physical and optical properties[106]. The major disadvantage of polymers is their variable permeability to light, gases, vapours and low molecular weight molecules[107], any of which can have detrimental effects on the products they contain but are dependent on the type of material used.

Thermoplastics are polymers that soften on exposure to heat and return to their original condition at room temperature. These materials can easily be shaped and moulded into various products such as bottles and films, they are ideal for food packaging[108, 109]. The use of polymers in food packaging has continued to increase due to the low cost of materials and enhanced functional properties, such as ease of thermo-sealing and optical properties. The key to successful packaging is to select the package material and design features that best satisfy competing needs in regard to product characteristics, environmental and waste management issues and cost.

Considerable effort goes into selecting the right container for packaging and for manufacturers, packaging is a strategic decision. The following variables should be considered when choosing a container's design:

1. Protection against damage or contamination by micro-organisms, air, moisture and toxins – Products must be safeguarded against irregular transport and possible adulteration through tampering as well as ensuring they meet any physical, chemical or biological needs of the product they contain.
2. Prevention of product spilling or leaking – Packages must be tightly sealed and made resilient to ensure the product remains uncompromised at all stages of distribution until opened by the consumer.
3. Product Identification and Labelling – Nutrition, ingredients and sell-by dates are important not only to the consumer, but to retailers as well. All labelling must meet regulations requiring nutritional and allergen information. Additionally, traceability of the product is crucial and aids quality control of products.
4. Marketing of Product to Consumers – The integrity of the product is extremely important, but marketing and aesthetics are similarly important. In addition to containing and protecting the item, the packaging must inform a buyer that ultimately leads to a sale. Containers that can achieve an extra-value message can set any product apart from its competitors. Ultimately, the package is the last opportunity for manufacturers to sell their product to consumers.
5. Sustainability of Packaging Materials – Increasingly, sustainability of materials used in packaging is becoming a critical decision for manufacturers. Over recent years this has been driven by consumer concerns over damage to the environment and the use of fossil-based materials[110].

7.3 Protection and preservation of products; key determinants in packaging decisions

Food packaging can delay product deterioration, retain the beneficial effects of processing, extend shelf-life and maintain or increase the quality and safety of food. In doing so, packaging provides protection from three major classes of detrimental external influences: chemical, biological and physical effects.

Chemical protection minimizes compositional changes triggered by environmental influences such as exposure to gases, most notably oxygen, moisture (gain or loss), or light degradation of nutrients and includes; visible, infrared, or ultraviolet light. Closure devices may contain materials that allow minimal levels of permeability, for example, plastic caps have some permeability to gases and vapours, as do the gasket materials used in caps to facilitate closure. Plastic packaging offers a range of barrier properties but is generally more permeable to gas exchange. A major advantage of plastic packaging compared to metal, paper or glass is being lightweight.

Biological protection provides a barrier to microorganisms such as pathogens and spoiling agents. Additionally, biological barriers maintain conditions to control ageing of the product[95]. Such barriers function through multiple mechanisms, including preventing access to the product, preventing odour transmission through ingress and can maintain the internal environment of the package[111].

Physical protection shields food from mechanical damage and includes cushioning against shock and vibration encountered during distribution. Good design and optimised packaging systems help to avoid food loss and waste and can reduce the environmental burden of packaging material[94].

8.0 New developments in light-protective materials to preserve nutrients in milk

Packaging of dairy products develops continuously along with advances in material technologies, which are in turn a response to the demands of consumers. The nature and characteristics of the dairy product to be packaged will define the selection of the appropriate packaging material.

Studies have been undertaken on retail lighting systems and consumer acceptance of milk. One study by Potts and co-workers (2017), examined the effects of fluorescence and LED lighting stored under retail conditions through sensory assessment techniques[112]. This study looked at a range of packaging materials including PET packaging and translucent HDPE, white HDPE and yellow HDPE packaging materials. The results showed that both PET and HDPE when exposed to fluorescence light negatively influenced flavour profiles of milk. Analysis of dissolved oxygen content was used as an indicator of oxidation processes in light exposed milk samples and supported the observed differences in consumer acceptance of milk. The adverse effect of fluorescence light on milk quality has been well documented in primary research studies[113]. Martin *et al* (2016), reported the effect of LED light exposure at 1200 lx over 4 hours incurred a slightly reduced taste acceptability score with a consumer panel[114].

In recent years, considerable research efforts have been devoted to biodegradable or compostable food packaging materials, due to increasing awareness of issues such as shortage of oil resources, environmental protection and food safety[115, 116]. With this in mind, new developments in bio-based materials, for example using polylactic acid (PLA) have attracted significant attention. PLA is attractive due to its compostability, excellent biocompatibility and transparent optical properties.

Developments in composite bio-based materials have enabled the production of packaging with barrier properties and shelf-life performance that matches or exceeds older fossil carbon-based polymers. Forms of active packaging relevant to dairy foods include oxygen scavenging from headspace gasses; moisture and/or flavour/odour taint absorbers; maintenance of temperature control and/or compensating temperature changes and antimicrobial packaging. The greatest challenge from an environmental point of view is biodegradable packaging. The main challenges for low waste materials are the durability of the packaging materials associated with product shelf life and safety of new bio-based materials[117].

The efficacy of light-protective additive packaging to protect milk freshness on exposure to LED lighting in a retail setting was recently published by Wang and co-workers in 2018. This study presented data indicating that exposure of 2% milk to a light intensity of 1068 lx induced light oxidation especially in HDPE packaging material after 4 hours of exposure. Light exposure at higher intensity of 4094 lx, significantly increased the oxidation rate in milk. Milk packaged in polyethylene terephthalate (PET) containers that have a lower oxygen permeability rate versus other typical polymers, significantly reduced the degradation of vitamin A. Light-protective TiO_2 in combination with an oxygen barrier material (PET) reduced the loss of dissolved oxygen and importantly riboflavin was preserved[60]. Interestingly, in this study it was found that 50% of participants in a visual acceptance test, preferred milk displayed at lower LED intensity. Furthermore, they were prepared to consider pigmented packaging materials with limited transparency.

A recently published study by Parit and co-workers (2018), prepared UV-protective films using lignin from the pulp and paper industries and cellulose nanocrystals. The work demonstrated that lignin modification through acetylation reduced the lignin colour and improved visible light transmission of the produced films without significantly affecting the UV-absorption properties. This development has the potential to be tested as a film covering for food packaging materials with UV absorption properties[118].

Some significant work has recently been published using a wide variety of bio-based materials showing light-protection qualities. Although these new materials show promise across a range of application areas, including packaging materials, the research is at an early stage of development. For example, a recently published study by Wu *et al* (2019) developed a biodegradable UV shielding material using titanium dioxide (TiO_2) lignin particles as a poly(propylene carbonate) (PPC) composite film that can absorb approximately 90% UV light (λ200 – 400nm)[119]. Although not yet developed in packaging materials, it has the potential to be further exploited. A further recent study by Balasubramanian and co-workers (2019) have developed a specific hydrogel composite film for packaging using k-Carrageenan, xanthan gum and gellan gum impregnated with TiO_2[120]. This material showed good tensile strength and thermal stability with increased UV protective properties.

Furthermore, an interesting study by Stoll and co-workers, developed a PLA film with carotenoids (beta-carotene, lycopene and bixin)[121]. In the presence of light, the newly developed films showed light barrier properties and enhanced oxygen barrier functions. Further research is needed on these films, but they potentially could be used for protection of milk products. Currently, high-performance packaging materials featuring superior gas barrier and UV resistance as well as robust mechanical properties are desirable in the food packaging arena.

In a further study by Yousefi *et al* (2019), a novel cross-linked wheat starch based ternary nanocomposite film with sodium montmorillonite and TiO_2 was developed[122]. Nano-TiO_2 blocked the UV light effectively and >99% of UV was removed by the film containing 4% TiO_2, showing potential for use as a packaging material.

The characterisation of bacterial cellulose films utilising chitosan and polyvinyl alcohol was recently investigated by Cazón and colleagues[123]. The developed films showed UV light barrier properties and had an enhanced visual appearance, with potential for food packaging applications.

The properties of a newly developed film using nano-silver (nano-Ag) and PLA composite films has been investigated [124]. Results indicated improved barrier properties, although with increased time and pressure testing, the rate of migration of the nano-Ag was increased, this finding could therefore limit the safety of this material in food packaging applications. Hayden *et al* (2019) have investigated the properties of a broadband UV-blocking transparent composite nanopaper film using cellulose nanofibrils[125]. The potential for coating packaging material with this composite film for high-performance, renewable and biodegradable applications is interesting and is currently under further investigation.

A recent study by Ni and co-workers (2019), investigated improved functionality of starch using glyoxal and ammonium zirconium (AZC) as a crosslinking agent[126]. This study revealed enhanced mechanical and UV blocking capacity as well as increased mechanical strength, which is a point of concern for many new composite materials.

New developments and technological advances for enhanced packaging materials remains a robust area for research. However, before adoption of new technologies, confidence in the safety and durability must be evidenced. Within the European Union and the UK, materials and articles in contact with food must demonstrate compliance with existing regulations. The general requirements are addressed in the framework regulation (Regulation (EC) No. 1935/2004) with additional regulations for specific materials with special requirements such as plastics (Regulation (EU) No. 10/2011) and active and intelligent packaging (Regulation (EC) No. 450/2009). Additional regulations to protect the consumer include adherence to Good Manufacturing Practice, quality assurance and quality control, traceability and labelling.

Overview of Key Points for Packaging

- **Packaging only exists because products exist**
- **First & foremost it's a delivery system for products**
- **Its primary role is to contain, protect and preserve**
- **A primary mechanism for branding of products and informing the consumer**
- **Packaging extends the shelf-life of products and reduces food waste**
- **Modern society couldn't function without it and it's an inevitable and necessary feature of modern living**
- **Demand for packaging is created solely by the demand for the products that it contains**
- **Consumers expect to have everything available 24/7 – this is only possible with modern packaging**
- **Packaging that has been certified as light-protective and certified can increase consumer confidence in the product**

9.0 Technology to Protect Milk from Light Exposure

Over 3 billion milk containers are produced each year in the UK, with the major supermarkets supplying around 62% of all milk sold. Most are kept in well-lit refrigerated display cases that use LED or fluorescence lighting sources. The appearance of the bottles is either translucent or coloured, mostly using white pigments as optical brighteners, the material is either polyethylene terephthalate (PET) or high-density polyethylene (HDPE).

Current innovations such as the development of PET or HDPE with light protective additives have been shown to successfully reduce loss of vitamins in milk and maintain the duration of fresh taste. However, research has revealed that a white bottle appearance alone does not mean that a bottle is light protected and the few clear glass bottles on the market offer no light protection at all. Early attempts used brown bottles[127] with limited success and from an aesthetic viewpoint brown or heavily coloured glass would be unacceptable to consumers today. New technology incorporated into bottles has been developed by scientists[60, 128, 129], that significantly protects the delicate light sensitive nutrients in milk products. Extensive sensory testing by panellists at Virginia Polytechnic Institute & State University (Virginia Tech)[60, 100, 129], show that the natural flavour of milk is retained by products stored in the new bottle design and quality, nutrient content and freshness can be retained for longer. This would lead to a reduction in wastage of milk, thereby reducing overall food wastage.

In an older study, Saffert and co-workers (2009), evaluated the effect of package light transmittance on the vitamin content of milk, using UHT low-fat milk. The milk was stored under light with an intensity of 700 lx in polyethylene terephthalate (PET) bottles with varying light transmittance to monitor the changes in vitamins A, B_2 and D_3 content over a storage period of 12 weeks at 23°C[130]. Their findings showed that milk packed in pigmented PET bottles with the lowest light transmittance and stored in the dark, served as the 'control' sample. In clear PET bottles, a reduction of 93% of the initial content was observed for vitamin A and 66% for vitamin D_3, while the vitamin B_2 content was completely degraded. In all pigmented PET bottles, the vitamin retention was only slightly higher; the losses ranged between 70% and 90% for vitamin A, between 63% and 95% for vitamin B_2 and between 35% and 65% for vitamin D_3 depending on the pigmentation level. In the dark-stored 'control' sample, a 16% loss could be observed for vitamin A, while the level of vitamins B_2 and D_3 remained almost stable, this was explained as natural vitamin losses incurred through extended storage time.

Recent advances include an interesting study by Orsuwan and colleagues (2019), who have developed a novel low-density polyethylene (LDPE) film where they have embedded riboflavin into the film as a light absorber which filters light in the ultraviolet and short-visible regions (λ200 – 500nm)[128]. Although this film was developed to initially protect olive oil products, it would be interesting to explore the possibility of this type of film embedded into packaging for milk.

Milk Wastage in the UK

A recent report by WRAP (2018), indicates that 490 million pints of milk are wasted by households in the UK at a cost of £25 million each year[110]. A switch to certified light protective packaging has the potential to help reduce at least a portion of this wastage, by reducing the formation of off- flavours and ensuring consumer acceptance.

10.0 Importance of Product Labelling

Consumers increasingly depend on accurate information on product labelling. Nutrient content on pack labels is required by law in the UK and Europe and misleading claims can lead to complaints and possible legal action. Nutritional information must be accurate and clearly displayed on product labels.

One of the most general rules of European legislation on food labelling can be stated as “not misleading the consumer” (the protection of consumers’ interests is one of the principles of food law, as stated in Regulation 2002/178/EC). This applies to information concerning the characteristics of foods (nature, identity, properties, composition, quantity, storage life, origin, method of production or manufacture). Subsequently, Regulation (EU) No 1169/2011 on the provision of food information to consumers came into force on 13 December 2014 and the obligation to provide nutritional information from 13 December 2016. The labels should not attribute to the food, effects or properties which it does not possess. In the case of milk exposed to light degradation, nutrient content as stated on pack labels may not be correct over time, thereby giving a false statement on nutrient values.

11.0 Certification of Light Protection Materials

An influential study on light protection performance measurement technology aimed at dairy milk packaging was undertaken by Stancik and colleagues (2017). This persuasive study presented an accelerated measurement technology developed for quantifying packaging materials ability to preserve light-sensitive nutrients in fluid milk and is subject to a series of USA Patents[131-133]. The light exposure instrument measures changes in riboflavin after light exposure, to determine a light protection factor (LPF) for the tested materials as a performance metric. To further validate the method employed, measurement system analysis (MSA), was applied to ensure statistical robustness of the technique. Two detection procedures were employed to measure the riboflavin concentration in solution; an accelerated ex situ (AES) approach measured by high-performance liquid chromatography (HPLC) and an accelerated in situ (AIS) approach employing ultraviolet-visible spectrometry (UVS).

To test the application of this novel technology in packaging design, HDPE packages incorporating surface-treated TiO_2 pigments were subject to evaluation for light protection performance, either by AES or AIS. Under the test conditions riboflavin preservation was maintained for both retail and accelerated light exposure samples.

Noluma™ technical services and certification provides guidance for the dairy industry in the design of appropriate protective packaging materials to optimally minimise the degradation of milk nutrients and preserve flavour that can extend shelf-life and notably reduce waste. Consumers are becoming more aware of the detrimental effects of both retail light and indoor light on the nutritional and sensory quality of milk and they want to choose products that they can have confidence in. Noluma's™ patented technology is the only one of its kind that measures the light protective capability of packaging in relation to change in the contents. It helps companies quickly identify the optimal point of protection at which nutrients begin to decline. In order to ensure light protection claims are valid, Noluma™ International LLC, have developed unique state-of-the-art technology that can assess, measure and verify the light protection capacity of packaging claims.

This innovative approach employs a nutritional marker, riboflavin (vitamin B_2), the degradation of this marker is measured accurately to assess the protective capabilities of new packaging materials. Noluma™ then advises manufacturers on technical design features that can ensure optimum light protection. The Noluma™ certificate of performance is gaining recognition from discerning consumers as a marque of quality and assurance that consumers are looking for, giving them reassurance that the product they purchase contains the vitamins and nutrients promised as stated on the product label.

12.0 Conclusions

When consumed according to appropriate national guidelines, milk and its derivatives contribute essential macro- and micronutrients to the diet, especially in infancy and childhood where bone mass growth is in a critical phase[13]. Furthermore, preliminary evidence suggests potentially protective effects of milk against obesity, diabetes and cardiovascular disease. Overall, current scientific literature recommends that the appropriate consumption of milk, according to available nutritional guidelines, may be beneficial across all age groups, with the exception of specific medical conditions such as lactose intolerance or milk protein allergy.

It has been demonstrated extensively that exposure of food or drink to light from any source has negative effects, such as loss of vitamins and protein degradation[60, 128, 134]. In dairy products, especially milk, compelling evidence has been presented that exposure to a spectrum of wavelengths is responsible for a significant loss of essential micronutrients required for human development and health[135]. Recent studies have shown that exposure of milk to light from any source causes a loss of vitamins such as riboflavin (vitamin B_2)[136]. Other effects on the nutritional properties of milk have included changes in levels of retinol (vitamin A)[137]; cholecalciferol (vitamin D_3)[138, 139]; ergocalciferol (vitamin D_2)[140]; cobalamin (vitamin B_{12})[141]; pyridoxine (vitamin B_6)[142]; ascorbic acid (vitamin C)[100, 101, 112, 113, 143] and protein[144-146]. Additionally, organoleptic changes have been identified, such as changes in taste and aroma that may lead to increased wastage of milk as consumers associate the flavour profile changes as detrimental to the product.

It is evident that packaging materials with appropriate light protective capabilities are required for milk to minimise product damage and loss of nutrients. Manufacturers of packaging materials should also consider certification of their packaging to ensure that sourcing of raw material for packaging and storage conditions are optimised to preserve the nutrient value of milk. Furthermore, as consumers become more aware of the issues of light degradation of essential nutrients in milk, they will increasingly look for certified packaging that can ensure milk products retain their nutrient value.

13.0 Recommendations

The results of this review indicate that in response to the ongoing innovation in light protection technologies for milk packaging, implementation of certified packaging materials would help retailers and manufacturers of packaging containers have assurance in the products they sell. Additionally, this would significantly increase consumer confidence when purchasing milk.

Manufacturers and retailers need to be aware of the detrimental effects of light exposure on the nutritional quality and sensory properties of milk. The implementation of strategies to control the exposure of milk to light should be considered to ensure consumer satisfaction and to help contribute to a reduction in food waste.

For milk, exposure to light in the visible region with wavelengths generally under λ500nm should be minimised. This can be achieved partly through a consideration of the design and lighting used for retail display cases and partly by selection of appropriate packaging.

Packaging material with optimal light barrier properties that can prevent food quality deterioration should become standard in the dairy milk industry. For dairy products, package design should protect package contents, in particularly riboflavin and chlorophyll from the detrimental effects of light. Retailer and consumer confidence in the effectiveness of the packaging can be enhanced through the use of certified packaging materials.

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New Technological Advances

Whilst all of the new advances and developments in technology for packaging materials remain an active research area, it should be noted that these new materials must undergo significant developmental testing to ensure safety first and foremost. Furthermore, all new materials prior to use by industry, should undergo full certification to ensure that any claims made regarding light-protective capabilities are valid and robust.

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Appendix 1

Scientific literature search terms:

- Light effects in milk
- Light activated flavour development in milk
- Light stability of vitamins in milk
- Protein degradation in milk and light
- Vitamin degradation in milk and light
- Photooxidation of nutrients and milk
- Light transmission in milk and shelf-life
- Riboflavin and fluorescence light

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https://worldwidescience.org/

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http://www.opendoar.org/

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